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FLIGHT-TEST INVESTIGATION OF A MODEL OF AN AERIAL VEHICLE SUPPORTED BY FOUR UNSHROUDED PROPELLERS

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SUMMARY

An investigation of the dynamic stability and control characteristics in hovering and at low forward speeds has been made on a small-scale flying model of an aerial vehicle supported by four unshrouded propellers that were fixed with respect to the airframe so that the propeller plane of rotation was horizontal for hovering flight. The model in its basic configuration consisted of a boxlike body in the center, with the four propellers mounted on struts around the body and guard rings mounted around the propellers.

The investigation showed that, in hovering, the uncontrolled (that is, controls fixed) pitching and rolling motions of the model were unstable oscillations. Inasmuch as the periods of the oscillations were relatively long, however, the model could be controlled fairly easily in hovering without artificial stabilization. In forward flight, the basic model required an increasing nose-down pitch trim and a nose-down attitude for drag trim as the forward speed increased. The magnitude of these changes was much lower than those experienced on similar shrouded-propeller configurations. The model had an increasing static longitudinal instability (unstable variation of pitching moment with angle of attack) with increasing forward speed, and had about neutral directional stability in forward flight. The addition of horizontal and vertical tails overcame most of these stability and trim problems in forward flight; therefore, the model had reasonably satisfactory stability and control characteristics.

INTRODUCTION

The National Aeronautics and Space Administration has investigated simplified models of several configurations that might be suitable for a light, general purpose VTOL aerial vehicle. As originally visualized, these vehicles would be able to hover or fly forward at speeds up to about 60 knots and would carry a payload of about 1,000 pounds. Basically they consist of a body for the engine, pilot, and cargo supported by two or more propellers that are either shrouded or unshrouded. The propeller

plane of rotation is horizontal for hovering flight, and for most configurations it is fixed with respect to the airframe.

The results of an investigation of an approximately 1/3-scale model of a vehicle having two fixed shrouded propellers are reported in references 1 and 2, and the results of a similar investigation of a model with four shrouded propellers are reported in reference 3. Two rather serious problems brought out in these tests, which have been found inherent in any simple shrouded-propeller configuration in forward flight (for example, ref. 1), are as follows: an undesirably large forward tilt angle required at the higher speeds and a nose-up pitching moment which increases rapidly with increasing forward speed.

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One approach to the problem of excessive tilt angles required for higher speeds is to tilt the shrouded propellers with respect to the airframe. Reference 4 gives the results of an investigation of a model that had three shrouded propellers in a triangular arrangement, one in front and two at the rear, that could be tilted with respect to the airframe. Another approach to the problem of the undesirable pitching-moment and tilt-angle characteristics of the fixed shrouded-propeller configurations is the use of unshrouded propellers because of the smaller pitching moment and drag resulting from translational velocity.

The present investigation was made with a model which had four unshrouded propellers that were fixed with respect to the airframe so that the propeller plane of rotation was horizontal for hovering flight. This paper presents the results of a series of free-flight tests performed in the Langley full-scale tunnel to obtain the dynamic stability and control characteristics of the model in hovering and in forward flight. The results were obtained mainly from pilots' observations and also from studies of motion-picture records of the flights. Reference 5 gives the results of a force-test investigation of this same model. Some of the results from reference 5 are compared with flight-test results herein.

SYMBOLS

The static longitudinal forces and moments are referred to the wind axes and the static lateral forces and moments are referred to the body axes. The axes originate at the center of gravity of the model.

F_{Y_β} variation of side force with angle of sideslip, lb/deg

M_Y pitching moment, ft-lb

M_{Y_V} variation of pitching moment with forward speed, ft-lb/knot

M_{Y_α} variation of pitching moment with angle of attack, ft-lb/deg

M_{X_β} variation of rolling moment with angle of sideslip, ft-lb/deg

M_{Z_β} variation of yawing moment with angle of sideslip, ft-lb/deg

i_t horizontal-tail incidence angle, positive when trailing edge is down, deg

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c chord of horizontal tails, ft

α angle of attack of fuselage axis relative to horizontal, positive when nose is up, deg

β angle of sideslip, deg

ϵ angle of downwash, deg

APPARATUS AND TESTS

Model

The basic model is shown in the photograph in figure 1 and the sketch in figure 2. The model was a simplified research vehicle that was not intended to represent any specific full-scale vehicle but the size was such as to represent approximately a 0.3-scale model of a proposed full-scale vehicle. The model was designed to have the same size cargo box and the same width (with the two-blade propellers lined up fore and aft and the propeller guard rings folded) as the models of references 1 to 3.

The model propellers were of laminated-wood construction and for most of the tests had fixed blade angles of 13° at the 0.75-radius station. For one series of tests the blades were set at other angles, as will be explained subsequently. The propellers were driven through gearboxes and interconnecting shafting by two pneumatic motors which were controlled by a throttle valve. The propeller guard rings were intended to protect the propellers without appreciably affecting the propeller characteristics and therefore were made of relatively small diameter tubing and located so as to provide a large tip clearance.

The normal center of gravity of the model was at the center of the model and in the plane of the propellers, but for a few tests the center of gravity was moved forward in the model.

The model was tested both with its long dimension as the longitudinal axis and with its short dimension as the longitudinal axis. As shown in figure 3(a) and figure 3(b), these two conditions will be referred to in this report as configurations A and B, respectively.

Figure 3 also shows the final configuration of the horizontal and vertical tail surfaces that were added to the basic configuration. The horizontal tails had an airfoil shape and were mounted outboard of the propeller guard rings. The vertical tails were flat plates and were mounted under the rear half of the rear propellers. Figure 4 shows one other horizontal- and two other vertical-tail configurations that were tried on configuration B during the investigation.

For all the tests, the model control moments (pitch, roll, and yaw) were provided by small compressed-air jets located at the side and rear of the model as shown in figure 2. These jet-reaction controls were operated by the pilots who controlled them remotely through the use of flicker-type (full on or off) electropneumatic actuators. These actuators were equipped with integrating trimmers which trimmed the control a small amount in the direction the control was moved each time a control deflection was applied. With actuators of this type, a model becomes accurately trimmed after flying a short time in a given flight condition.

The flicker-control moments used during the tests for configuration A were about ±13 foot-pounds in pitch, ±10 foot-pounds in roll, and ±7 foot-pounds in yaw. Total travel on the pitch jet-reaction control (flicker control plus trim) provided ±28 foot-pounds of moment, which gives a margin of ±15 foot-pounds of pitch trim before a reduction of flicker control occurred.

When the model was tested as configuration B, the flicker-control moments were about ±10 foot-pounds in pitch, ±13 foot-pounds in roll, and ±7 foot-pounds in yaw. For this configuration, total travel on the pitch control (flicker control plus trim) gave ±22 foot-pounds of moment.

The weight and mass characteristics of the model varied somewhat from one phase of testing to another as tails and ballast weights, for example, were added or removed. The following values are felt to be reasonably representative of average values for the model in configuration A and varied not more than ±10 percent during the tests except for the forward center-of-gravity tests:

Weight, lb	65
Moment of inertia about pitch axis, slug-ft^2	4.3
Moment of inertia about roll axis, slug-ft^2	4.0
Moment of inertia about yaw axis, slug-ft^2	6.2

For tests on the configurations having the most forward center of gravity (0.34 propeller diameter ahead), the moments of inertia about the pitch and yaw axes were increased about 20 and 15 percent, respectively.

Tests

The investigation consisted of flight tests to determine the dynamic stability and control characteristics of the model in hovering flight in still air and in forward flight up to a model speed of about 33 knots (60 knots, full scale). The model was tested in the basic configurations without tail surfaces and also with the various horizontal and vertical tail surfaces added to improve the stability and control characteristics at the higher forward speeds. Flight tests were also made with center-of-gravity locations of 0.16 and 0.34 propeller diameter ahead of the normal position at the center of the model in an attempt to improve the longitudinal stability characteristics in forward flight.

The model was tested in forward flight in both configurations A and B, that is, both with its long dimension as the longitudinal axis and with its short dimension as the longitudinal axis. The test results were obtained both from the pilots' observations and opinions of the behavior of the model and from subsequent study of motion-picture records of the flight tests.

Test Setup and Flight-Test Technique

Figure 5 shows the test setup for the forward-flight tests made in the Langley full-scale tunnel. The sketch shows the pitch pilot, the safety-cable operator, and the thrust controller on a balcony at the side of the test section. The roll and yaw pilots were located in an enclosure in the lower rear part of the test section. All these operators were located at the best available vantage points for observing and controlling the particular phase of the motion with which each was concerned. Motion-picture records were obtained with fixed cameras mounted at the side and at the upper rear of the test section.

The air to drive the propellers and for the jet-reaction controls was supplied to the model through flexible plastic hoses, and the power for the electric solenoids was supplied through wires. These wires and tubes were suspended from overhead and taped to a safety cable of 1/16-inch braided aircraft cable from a point approximately 15 feet above the model down to the model. The safety cable, which was attached to the model at the center of gravity, was used to prevent crashes in the event of a power or control failure or in the event that the pilots lost control of the model. During flight the cable was kept slack so

that it would not appreciably influence the motions of the model during the normal course of the tests.

The test technique is best explained by describing a typical flight. The model hung from the safety cable with the tunnel airspeed at zero; the power was increased until the safety cable became slack and the model was in steady hovering flight. The tunnel-drive motors were turned on and the airspeed began to increase. As the airspeed increased, the pitch pilot applied nose-down control and trim to tilt the model to the required attitude; the power operator adjusted the power to the model fans in order
to provide the thrust needed to balance the forces on the model and to L
keep the model as near as possible to the center of the test section. 1
Steady level flights were also made at intermediate speeds so that the 7
stability and control characteristics at constant speed could be studied. 2
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Hovering-flight tests were made by using the same technique and setup except that the tunnel test section was not needed nor used. The tests were performed in a large enclosed area (one of the return air passages of the Langley full-scale tunnel) which provided protection from random disturbances due to wind and was large enough to reduce the slipstream recirculation effects to negligible values.

RESULTS AND DISCUSSION

Hovering Flight

For purposes of discussion of the hovering phase of the investigation, only configuration A will be considered (long dimension as the longitudinal axis) since the only difference between configurations A and B is how the model is oriented in forward flight.

In hovering, the stability and control characteristics were about the same for both the pitching and rolling motions, as might be expected from the general similarity of the geometric and mass characteristics of the model about the two axes. The model could be flown fairly easily in hovering flight and could be maneuvered to any desired position. At times it was somewhat difficult to fly perfectly steadily, or to stop at an exact spot after a maneuver, because the model tended to translate or "slide" considerably as a result of very little change in angle of pitch or roll.

The most predominant dynamic stability characteristics of the model in hovering flight were the unstable oscillations in both pitch and roll. Time histories of typical uncontrolled (that is, controls fixed) oscillations in pitch and roll, obtained from motion-picture records of model flights, are presented in figures 6 and 7, respectively. In spite of

these characteristics, the model could be controlled fairly easily in hovering without artificial stabilization mainly because the periods of the oscillations were fairly long (about 4 seconds) and the control power was adequate. This controllability is in contrast to the results found on the shrouded-propeller models of references 1 to 3 where the strongly unstable rolling oscillations made the models extremely difficult to control without artificial stabilization. The rolling oscillations of the models of references 1 to 3 had very short periods, were very unstable, seemed to be predominately angular motions, and were very easily excited by translational movement or horizontal gusts. The instability and short periods, particularly, made the models extremely difficult to control by remote control. The oscillation of the present unshrouded-propeller model had a longer period, was less unstable, was a combination of translational movement and angular motions, and was not as easily excited by translational motions. The uncontrolled motions of these models in hovering depend principally on three factors: the response of the aerodynamic forces on the shrouded or unshrouded propellers to changes in translational velocity (the exciting or restoring moments), the model moments of inertia, and the model damping characteristics. Shrouded propellers inherently are more sensitive to translational velocities, and the models of references 1 to 3 had only one-third to one-half as much inertia about the roll axes as the present unshrouded-propeller model. Because of these differences, the present model was much easier to fly in roll, although it was the pilots' opinions that the model motions would have been easier to control or to position accurately if there were a little more change of angle (restoring moments) with translational movement.

A few hovering-flight tests were made with the tail surfaces shown in figure 3 installed on the model. Study of motion-picture records of these flights showed there was very little difference in the model motions in hovering with or without the tail surfaces installed. The pilots observed that if the tail surfaces made any difference at all it was to increase slightly the tendency of the model to "slide" or translate without angular changes. However, the pilots felt the changes were so small as not to affect materially the flying qualities of the model in hovering flight.

No difficulty was experienced in controlling the model in yaw. As might be expected, the model was neutrally stable about the yaw axis in hovering and could be controlled easily.

Model behavior in take-off and landing tests and in flights made very close to the ground was no different from behavior in flight well above the ground except for a slight reduction in power required near the ground, which is normal for propellers or rotors operating near the ground.

Forward Flight

Longitudinal characteristics.- The investigation showed that in forward flight, the general trends for both configurations A and B were the same and differed only in magnitude as might be expected from the mass and geometry of the two configurations.

As the forward speed increased, the models required an increasing nose-down moment for pitch trim and an increasing nose-down attitude for drag trim. At 9 knots (16.5 knots, full scale) configuration A required about 15 foot-pounds of nose-down moment for pitch trim and, as the speed increased, additional pitch trim was required at the expense of the flicker-control moment available in this direction. Finally, at a speed of about 18 knots (33 knots, full scale) the model became very difficult to control and experienced a fairly rapid nose-up divergence. The pilot felt that this divergence was caused by two factors. First, the trim requirement was so great that there was very little nose-down control moment left to arrest the nose-up motion; and, second, as the forward speed increased, the model seemed to have an increasing static longitudinal instability with angle of attack. At about 18 knots, if the model were disturbed or if a forward motion of the model were checked with a little nose-up change in attitude, the nose-up pitching moments apparently became so great that the available control could not arrest the nose-up motion within the limits of the tunnel test section and the model went through a motion that appeared to be a pitch-up divergence. Figure 8 presents the static longitudinal characteristics of the basic models as obtained from force tests. These data show that at 18 knots, configuration A required 24 foot-pounds of pitch trim, as compared with the 28 foot-pounds of control moment available, and had a static attitude instability of 0.6 foot-pound per degree of angle-of-attack change. The data also show that above 18 knots, the pitching moment did not increase further with increasing speed, but the attitude instability continued to increase with increasing speed. It was the pilots' opinion that even with more control available, the model would be difficult to fly at speeds above 18 knots (33 knots, full scale) because the rate of divergence caused by the attitude instability would be excessive. Configuration B had the same longitudinal characteristics except that the pitch-trim requirement and attitude instability were a little less than for configuration A, and therefore a higher forward speed of about 23 knots (41 knots, full scale) could be achieved.

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In order to improve the behavior of the model at the higher speeds, horizontal tail surfaces were installed on the model. The first tail tried was horizontal tail 1 shown in figure 4. This tail, mounted in the center and behind the model in configuration B, did not give any noticeable increase in stability. One reason was that the local flow at this point was at such a high downwash angle that at a speed of about 14 knots the tail trailing edge was deflected down 70° from the

horizontal just to be alined approximately with the local flow to keep from adding nose-up moments to the model. With the tail at this angle, the variation of its lift and drag with angle of attack probably did not contribute much to the aircraft stability. In addition, in the position behind the propellers, the variation of the downwash $d\epsilon/d\alpha$ was probably of such a nature as to make the tail virtually ineffective for stability. In an effort to remove the tail from the influence of the propeller downwash as much as possible, the horizontal-tail position shown in figure 5(b) was tried next, first with a tail semispan of 18 inches and then with the final 24-inch semispan shown in figure 5.

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It was found that the 18-inch-semispan tails afforded a definite improvement in stability and made the model easier to fly in the speed range from 15 to 20 knots where these tails were tested, but the pilot felt that the attitude instability was still bothersome. The tail semispan was then increased to 24 inches and various tail incidences were tried at forward speeds up to 35 knots (60 knots, full scale).

In general, the stability characteristics of configurations A and B with these larger outboard tails installed were about the same. At speeds above 15 knots, where the motions of the basic model with tails off were jumpy, the model was very difficult to fly; however, with the tails installed with incidences of either 20° or 25°, the model motions were very smooth and the model was easy to fly. The force tests of reference 5 (fig. 9) showed that with tail incidences of this order the model had attitude stability at forward speeds above 10 knots. The flight tests showed, however, that the model did have a mild dynamic instability. When the pilot refrained from giving control (controls fixed), the model developed a gentle unstable oscillation of fairly long period, somewhat like a phugoid oscillation.

Because of the large nose-down tilt angles experienced by the model in forward flight, it was found that a variable incidence tail would be required to obtain both good stability and good pitch-trim characteristics throughout the forward speed range. High tail incidences were not very effective for producing stability in the 10- to 20-knot speed range, evidently because the tail was stalled; low tail incidences did not contribute pitch trim at the higher speeds of the test. These trends are evident in the data of figure 9.

Another way to reduce the pitch-trim requirements in forward flight and to improve the stability characteristics was to move the center of gravity forward in the model. This procedure, however, resulted in a large unbalanced pitching moment in hovering flight which required that the propeller pitch be changed through a wide range for pitching control so that the front propellers could carry much more load than the rear propellers in hovering. It was decided to simulate a vehicle which used variable pitch propellers for pitch control by setting the model propeller

pitch before each flight (while on the ground) and finding the speed at which the model flew with the pitch-reaction control at neutral. By varying the propeller-blade angle settings in this manner it was possible to obtain trim pitching moments throughout the test speed range and to observe the stability of the model for each trim speed and center-of-gravity location. Configurations A and B were tested in this manner with center-of-gravity locations 0.16 and 0.34 propeller diameter ahead of the normal position at the center of the model.

With the center of gravity 0.16 propeller diameter ahead, the model
could be flown fairly smoothly through the speed range with careful pilot L
attention as long as no large disturbances were encountered. The pilots 1
felt, however, that the models still had attitude instability, but to a 7
lesser degree than in the case with the normal center-of-gravity position, 2
because the rates of divergence were lower. The fact that the model was 2
in pitch trim because of the differential propeller-blade settings also contributed to the greater ease of control because the full symmetrical flicker control was available to the pilot for correcting the random motions of the model. The pilot was of the opinion that with this center-of-gravity position, the ease of control was about the same in forward flight as in hovering.

With the center-of-gravity position moved forward 0.34 propeller diameter, the longitudinal characteristics of the model in forward flight were nearly the same as with the final 24-inch-semispan horizontal tails. The model was fairly easy to fly and the uncontrolled motions that developed were gentle unstable oscillations of fairly long periods. The pilots felt that the divergence rates were slightly higher with this center-of-gravity position than with the normal center-of-gravity position and the final 24-inch-semispan horizontal tails.

In trying to obtain satisfactory stability characteristics from movement of the center of gravity alone, propeller efficiency should be considered. In hovering, with the center of gravity moved 0.34 propeller diameter ahead of the center of the model, differential propeller-blade angle settings on the order of 14° between the front and rear propellers were required to trim the model pitching moments. With the front blades at 6° and the rear blades at 20°, a reduction of propeller efficiency was experienced on the order of 7 percent from that obtained with the basic 13° setting.

Reference 5 contains a comparison of the static pitching moment, nose-down attitude, and attitude stability of the present model with the model of reference 1. The main longitudinal differences between the two types were in the much larger (2 to 1.5 times larger) static pitching moment and nose-down attitude resulting from forward speed for the shrouded-propeller configurations. In forward flight, the dynamic longitudinal stability of the model was generally similar to that of the shrouded-propeller models of references 1 to 3.

<u>Lateral characteristics</u>.- The lateral stability and control characteristics of configurations A and B again were essentially the same, and unless otherwise noted the following comments apply to both configurations. The small differences in the magnitude of the forces and moments between the two configurations can best be determined from the force-test data reported in reference 5.

The most noticeable lateral characteristic of the model in forward flight was in sideslip. As the forward speed increased, the model became difficult to keep exactly alined with the wind and, if allowed to side-
L slip, was difficult to straighten out. The pilot felt that, at best, the
1 model had about neutral directional stability. Since the yawing motions
7 affected the rolling motions to some extent, this characteristic became
2 very objectionable to the pilots at forward speeds of around 13 knots
2 (23.5 knots, full scale) and above.

In an effort to improve the directional stability, the single upper vertical tail (tail 1 in fig. 4) was installed on configuration B. This tail afforded some improvement but was not adequate for smooth flight. Additional area was added to form vertical tail 2 (fig. 4). This tail gave adequate directional stability and made the lateral motions very easy to control.

Next investigated were the twin vertical tails mounted under the rear half of the rear propellers shown in figure 3. These tails, with a span of 9 inches, had the same total area as vertical tail 2 (approximately 2.35 square feet). With these tails, the model was very easy to fly and seemed to have a little more directional stability than it did with vertical tail 2. Figure 10 presents a summary of the static lateral characteristics of configuration B with and without these lower vertical tails installed on the model. These data show agreement with the flight tests results in that the basic model had about neutral directional stability and the tails gave considerable improvement. A few flights were made with the span of the twin vertical tails reduced to 4.5 inches (1/2 the original area) but the pilots felt that these tails were not adequate and were about equivalent to vertical tail 1.

The directional stability of the two basic configurations (without vertical tails) was improved to some extent by moving the center of gravity forward but the pilots felt that even with the most forward test position (0.34 propeller diameter), vertical tails were still needed to give satisfactory directional characteristics.

In roll, the basic model was about as easy to fly in forward flight as it was in hovering up to speeds of about 15 knots. This result was in contrast with the results reported in reference 2 in which the ducted-propeller tandem configuration experienced an increasing dynamic instability in roll with increasing forward speed. At speeds above 15 knots

the present model had the horizontal tails installed because of longitudinal considerations and the vertical tails installed because of directional considerations. With these tails installed the model was fairly easy to fly in roll over the entire test speed range up to 33 knots.

The roll pilot could get some indication of the effect of the final 24-inch-semispan outboard horizontal tails on the roll characteristics of the model in forward flight in the 15- to 33-knot speed range by comparing the tail-on flight tests with the tests made with the tail off and with the forward center-of-gravity positions. In these tests it appeared that the model was easier to fly in roll throughout the test speed range with the horizontal tails installed.

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CONCLUSIONS

On the basis of a dynamic stability and control investigation in the Langley full-scale tunnel on a free-flying model which had four unshrouded propellers that were fixed with respect to the airframe, the following conclusions were drawn:

1. In hovering, the uncontrolled (that is, controls fixed) pitching and rolling motions of the model were unstable oscillations. In spite of these oscillations, the model could be controlled fairly easily in hovering without artificial stabilization mainly because the periods of the oscillations were relatively long.

2. In forward flight, the basic model required an increasing nose-down pitch trim and a nose-down attitude for drag trim as the forward speed was increased. The magnitude of these changes, however, was much lower than those experienced on similar shrouded-propeller configurations.

3. The basic model became very difficult to control longitudinally at speeds above 18 knots, mainly because of static longitudinal instability with angle of attack which increased with increasing forward speed.

4. The basic model had about neutral directional stability in forward flight.

5. For reasonably satisfactory stability and control characteristics in forward flight, and particularly for speeds above 18 knots (33 knots, full scale), horizontal and vertical tails were required.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Air Force Base, Va., January 30, 1962.

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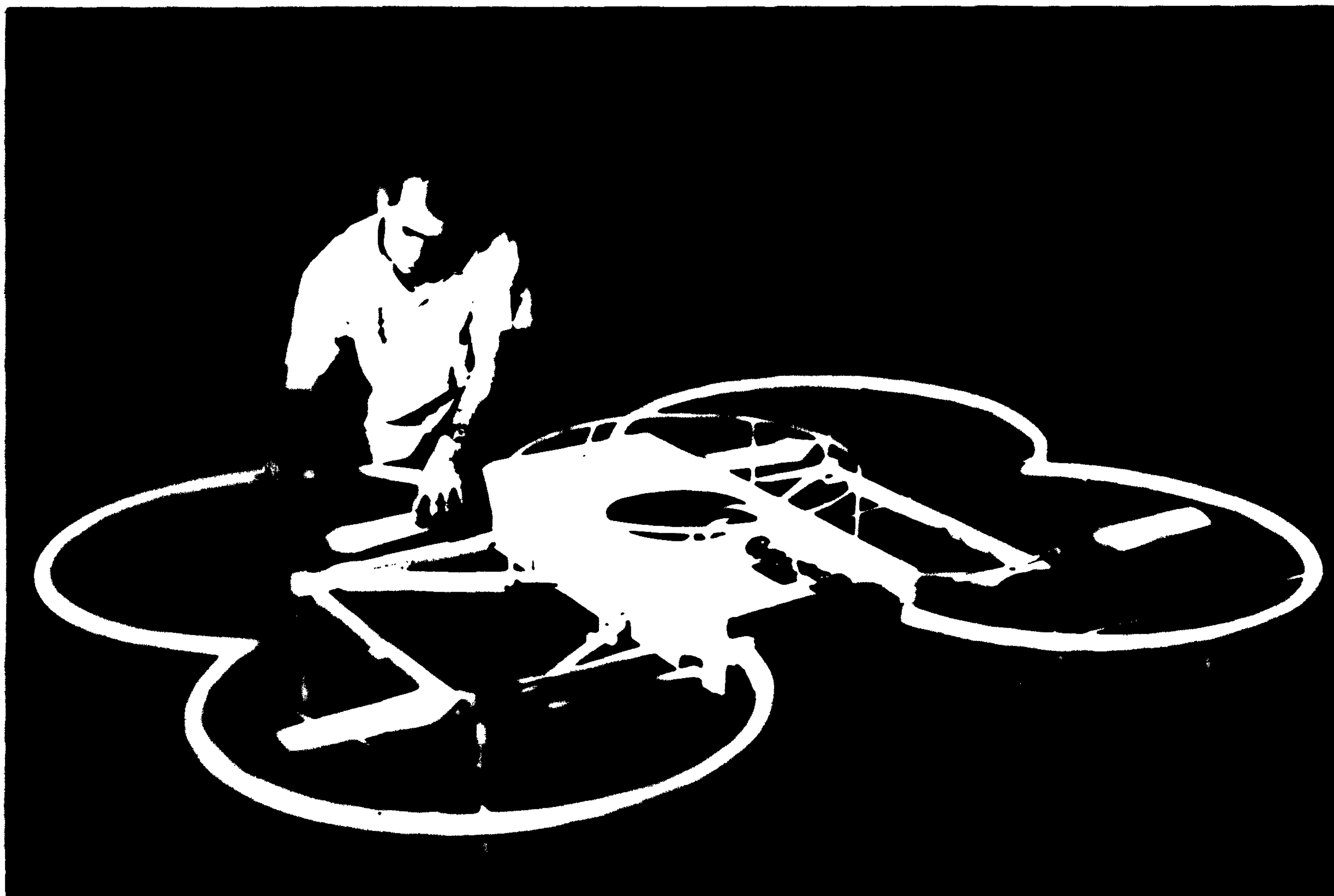

Figure 1.- Photograph of basic model. Jet-reaction controls not shown. L-59-3433

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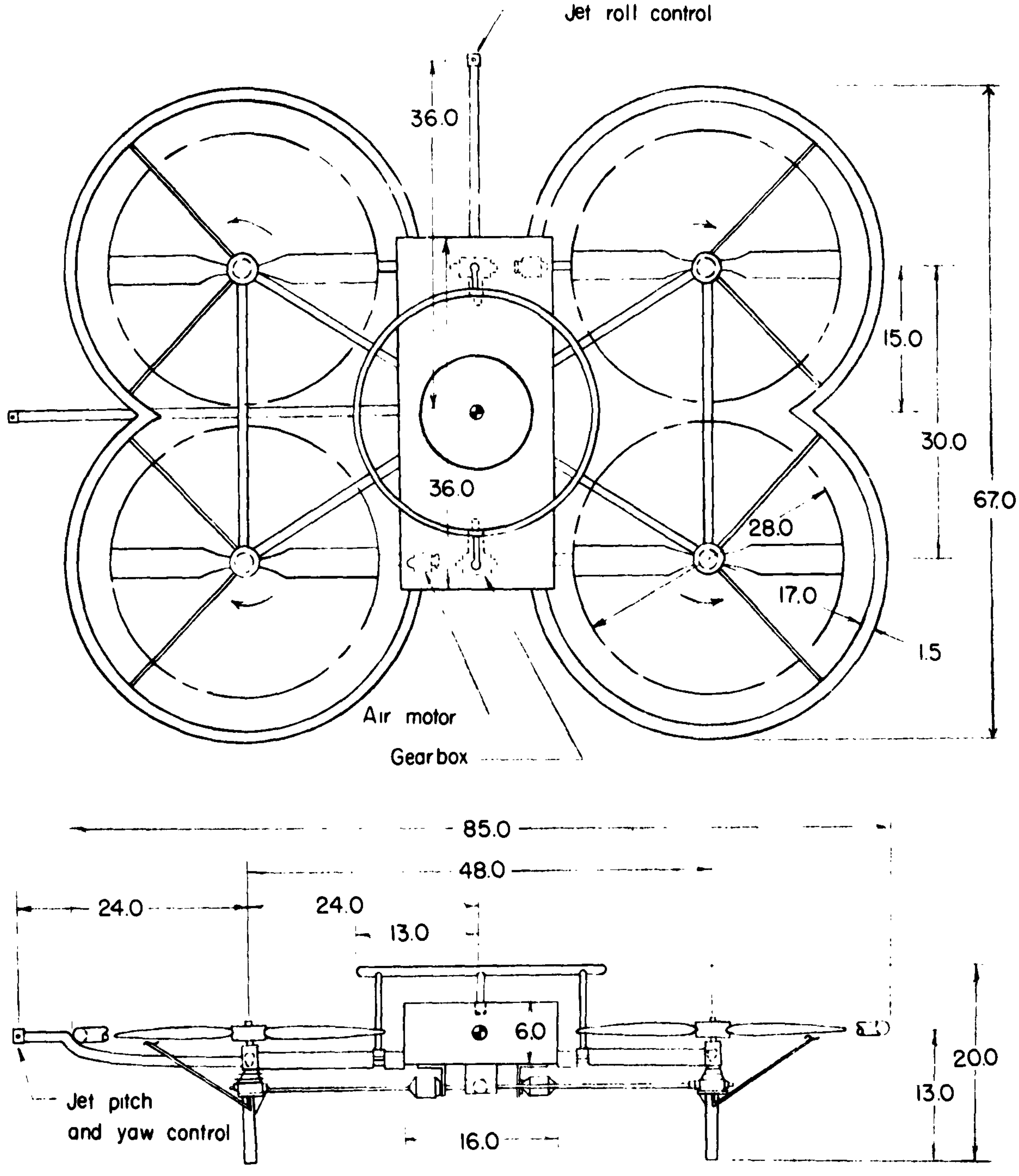

Figure 2.- Drawing of basic model. All dimensions are in inches.

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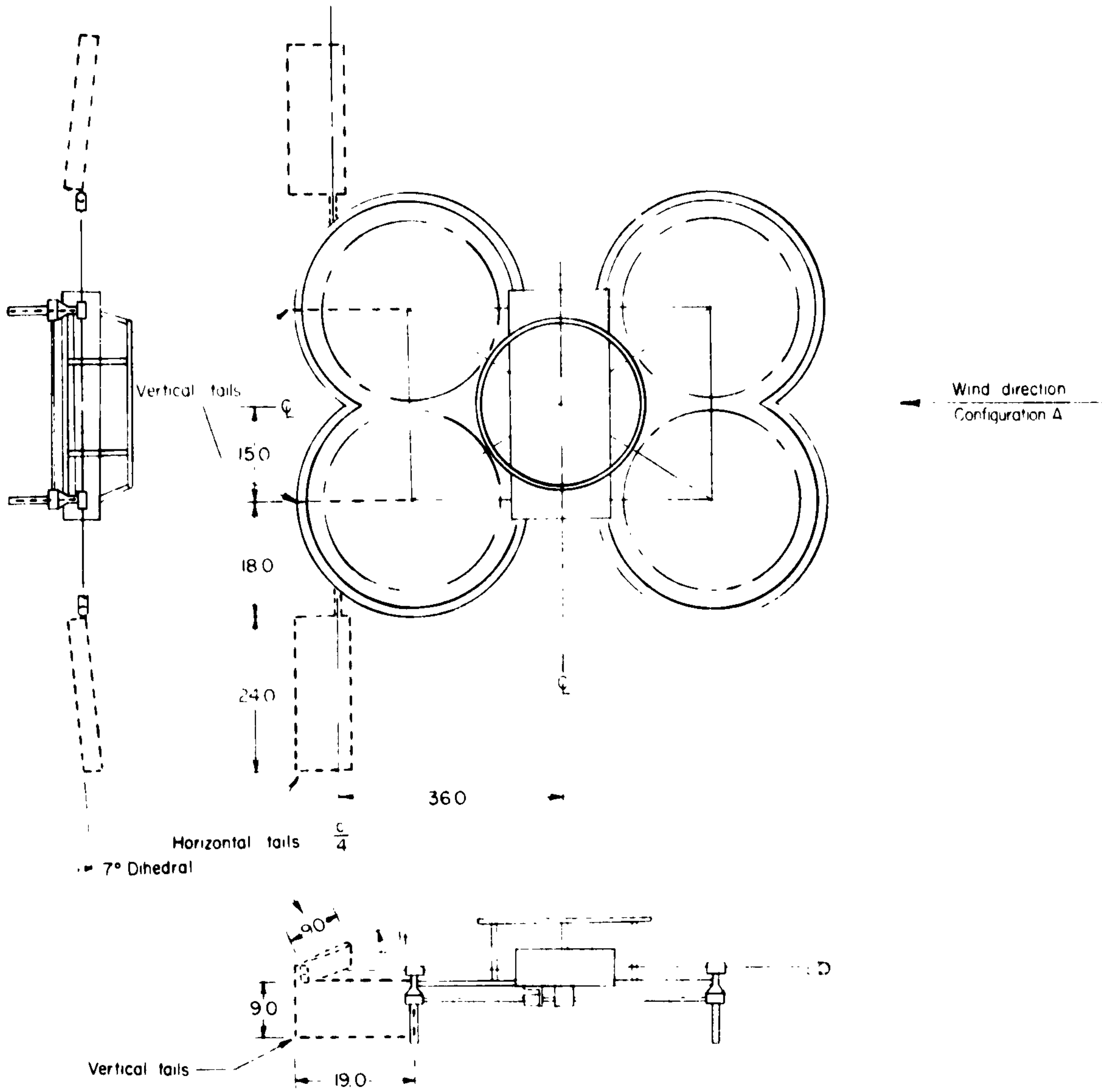

(a) Configuration A with tails on.

Figure 3.- Sketches of configurations A and B with final horizontal and vertical tails indicated by dashed lines. Jet-reaction controls not shown. All dimensions are in inches.

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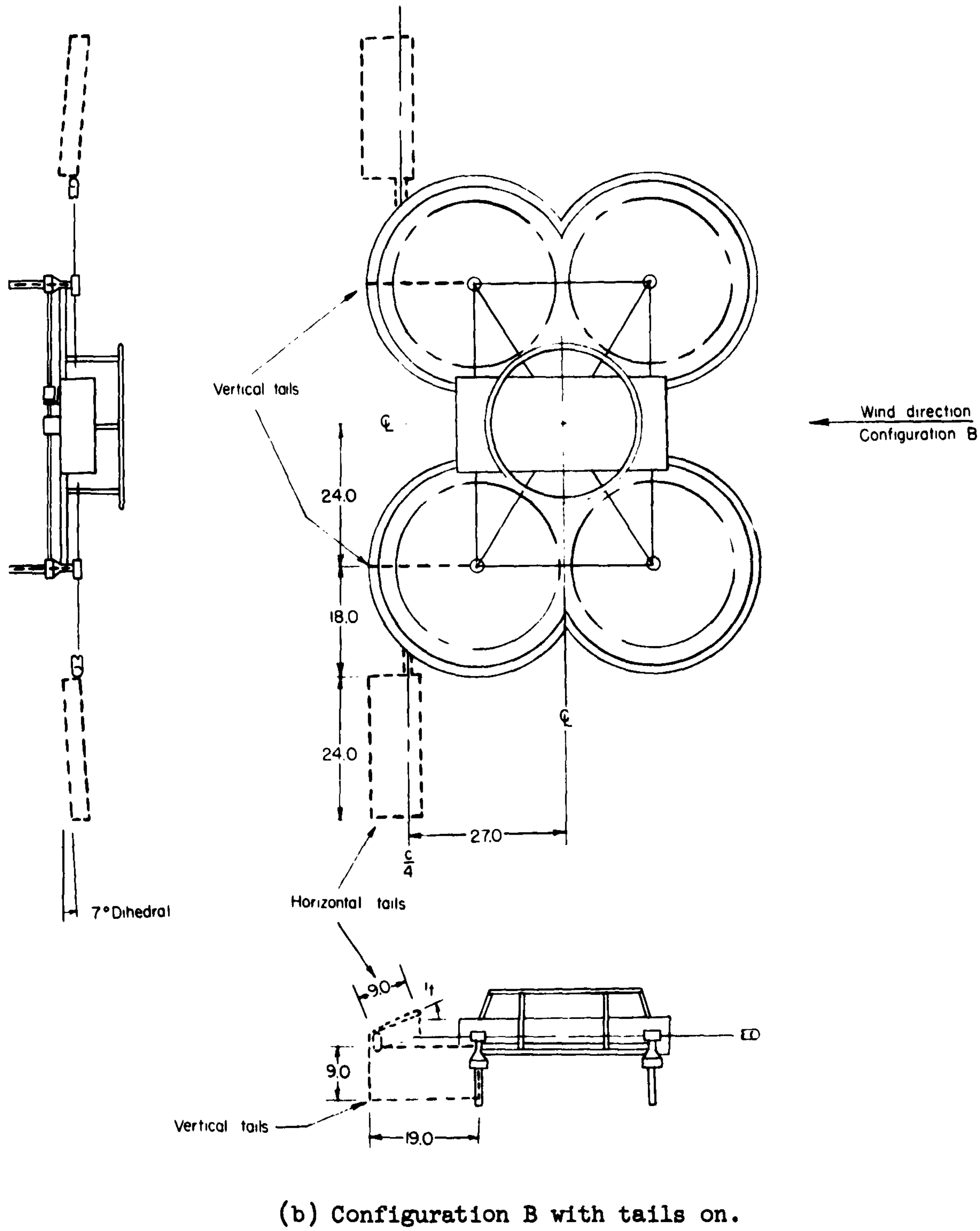

(b) Configuration B with tails on.

Figure 3.- Concluded.

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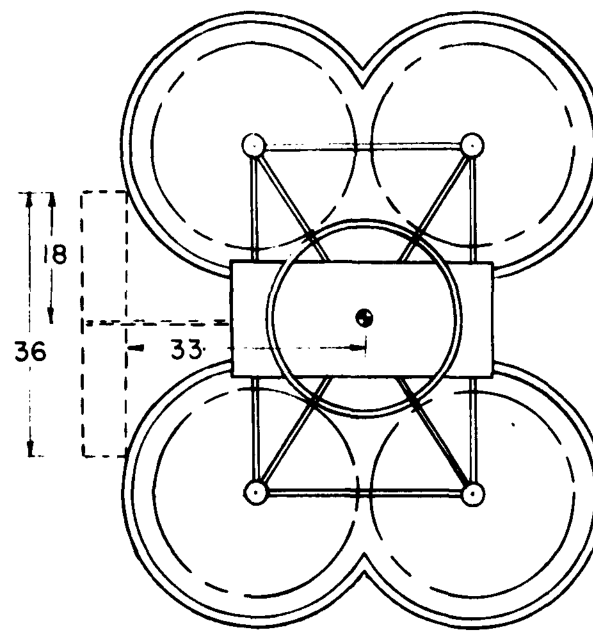

	Vertical tail dimensions	
	Tail 1	Tail 2
Root chord, inches	18	20
Tip chord, inches	9	8
Span, inches	18	24
Moment arm, inches (to $\frac{1}{4}$ M.A.C.)	26	27.5

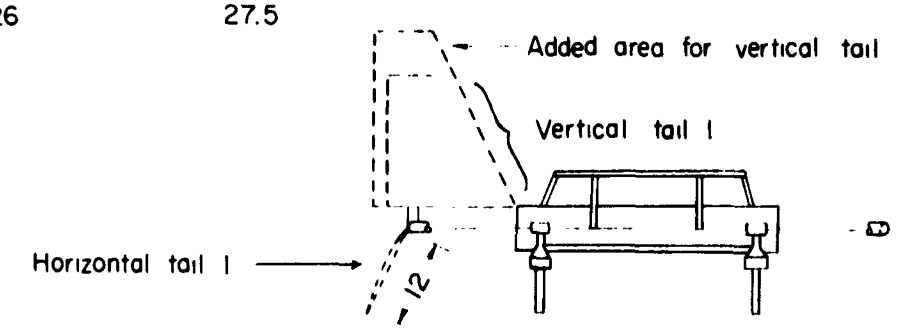

Figure 4.- Preliminary horizontal- and vertical-tail configurations investigated with configuration B.

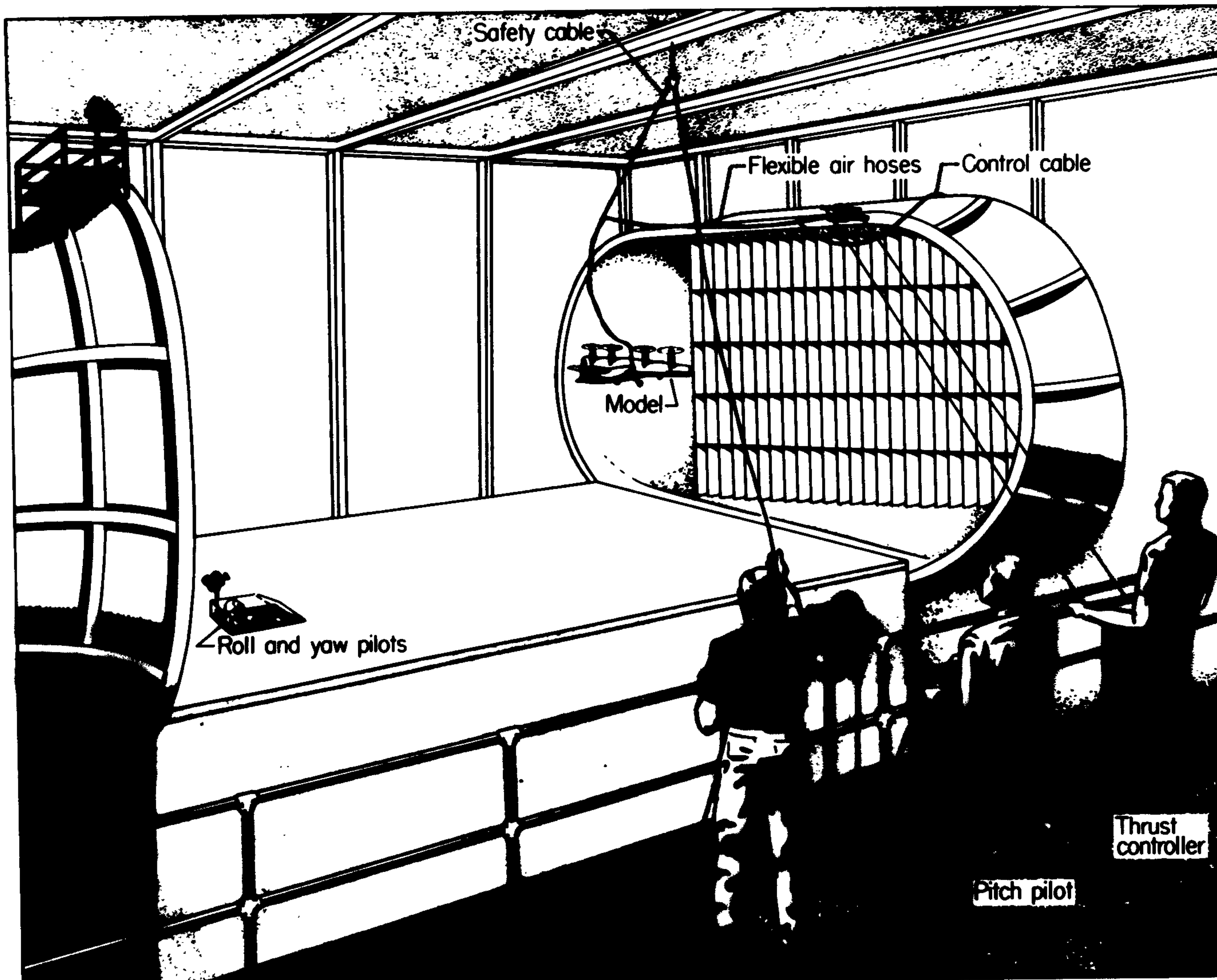

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Figure 5.- Typical setup used for forward-flight tests in the Langley full-scale tunnel.

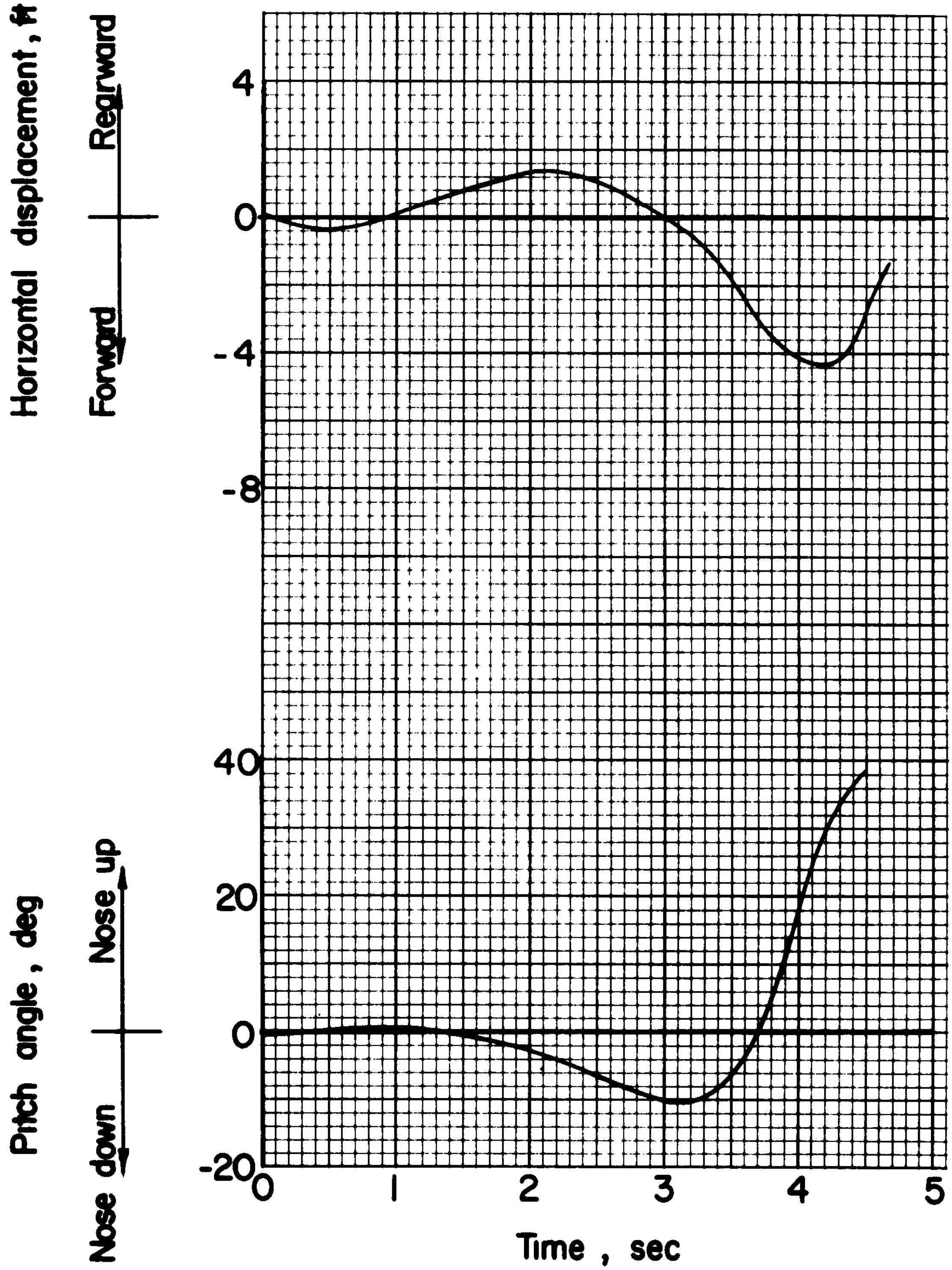

Figure 6.- Typical uncontrolled model pitching oscillations in hovering for configuration A.

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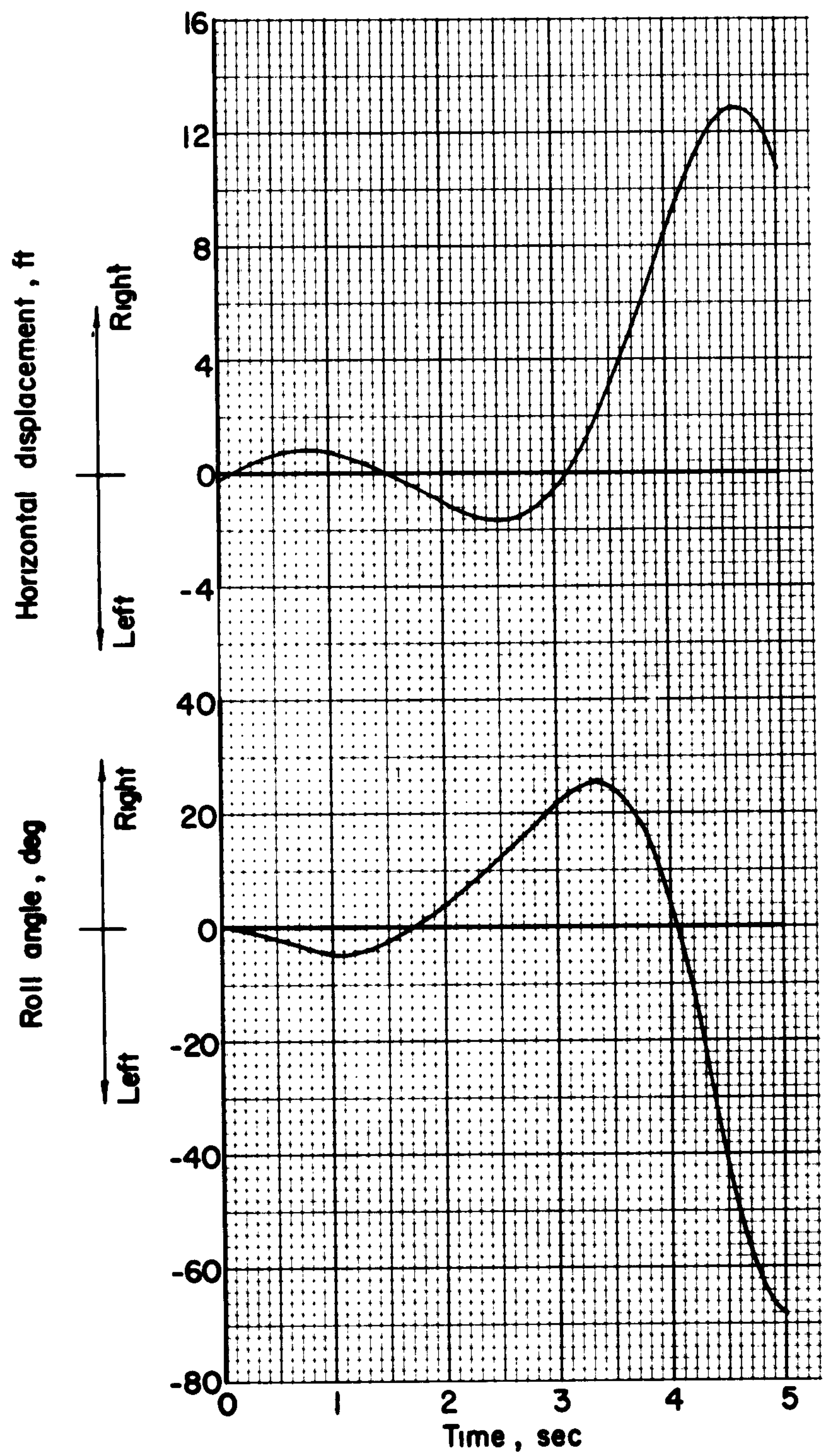

Figure 7.- Typical uncontrolled model rolling oscillations in hovering for configuration A.

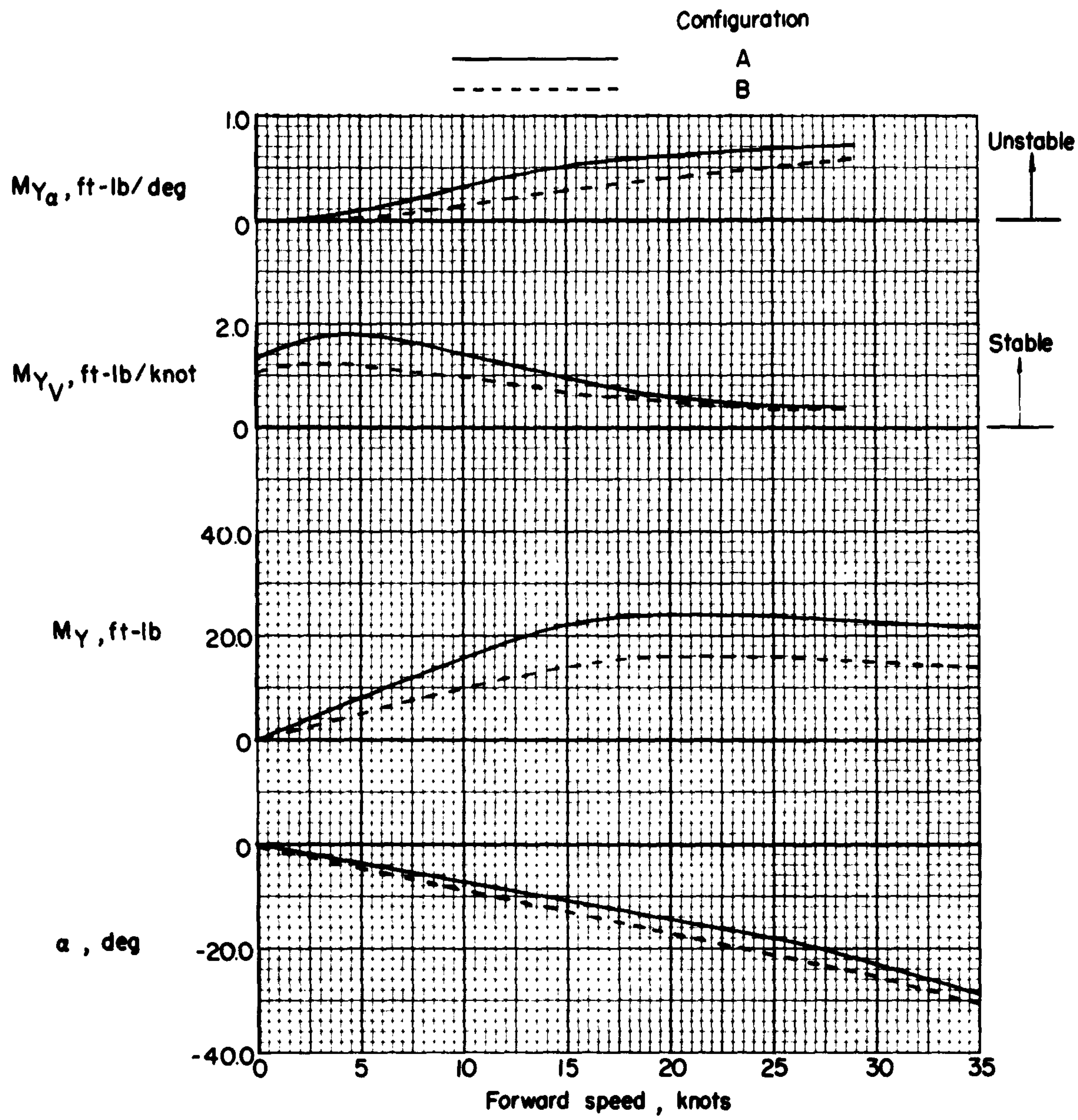

Figure 8.- Static longitudinal characteristics of basic configurations. No tails; zero drag. Reproduced from reference 5.

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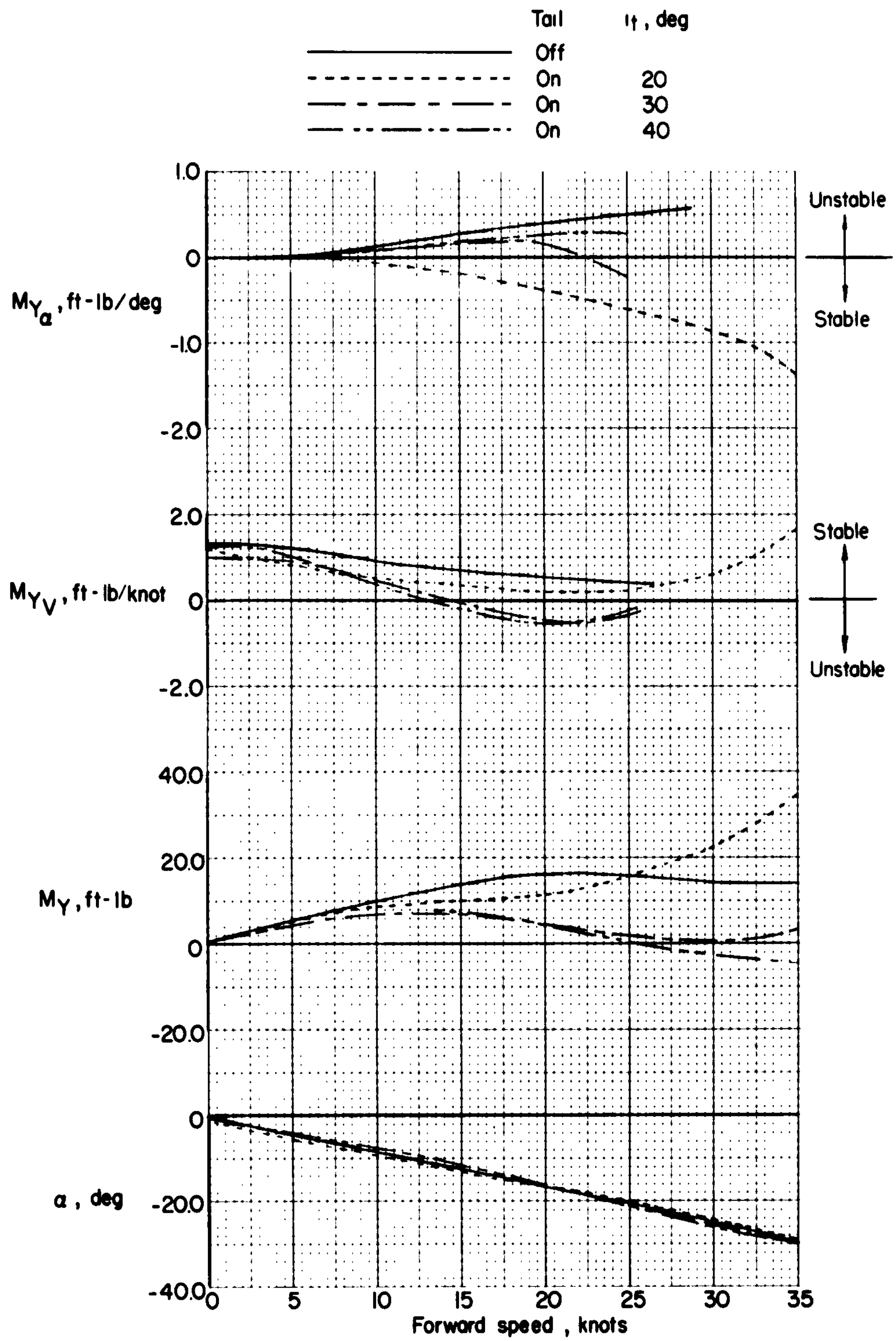

Figure 9.- Effect of horizontal tails on the static longitudinal characteristics of configuration B. Zero drag. Reproduced from reference 5.

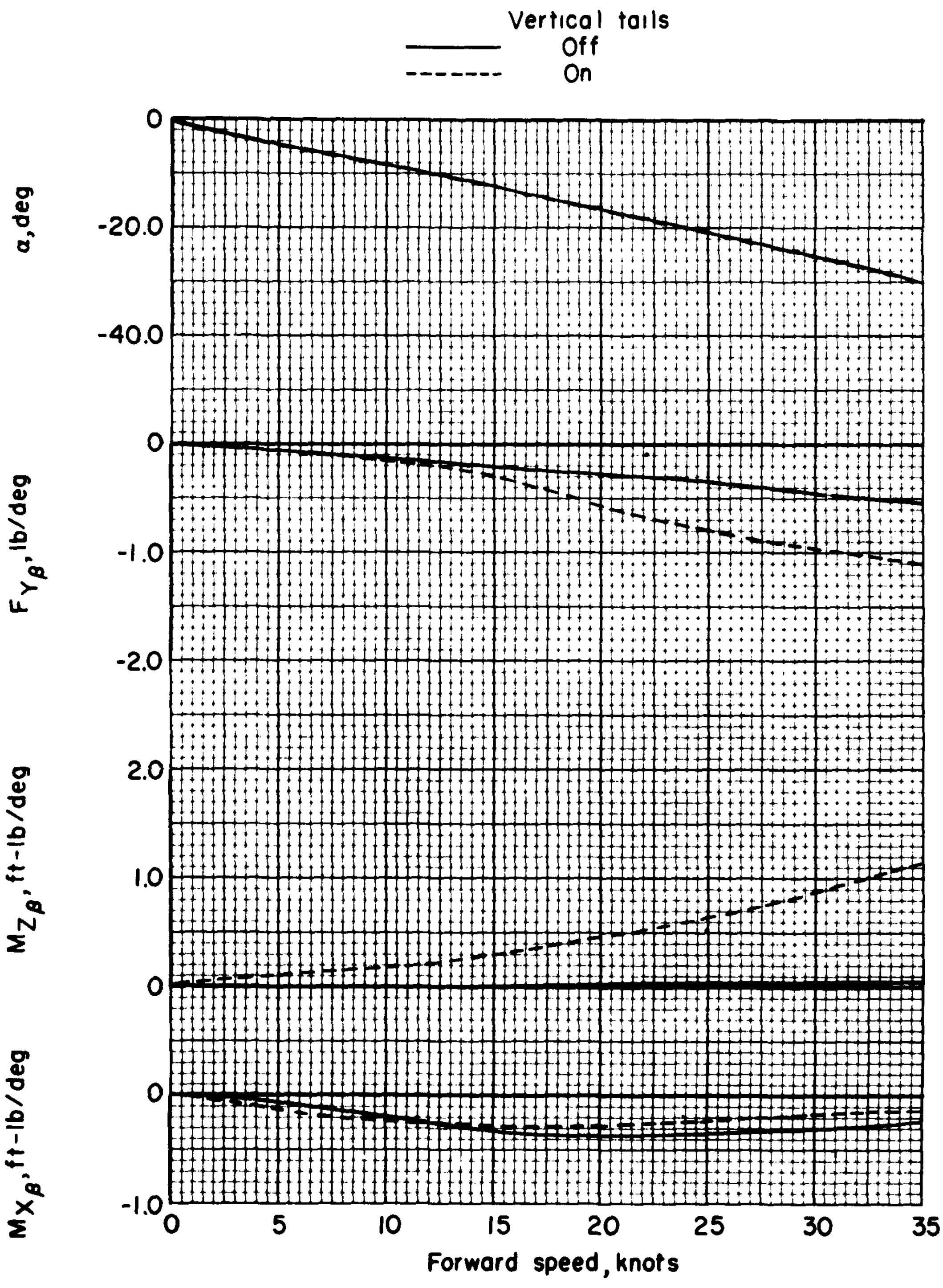

Figure 10.- Effect of vertical tails on the static lateral characteristics of configuration B. Zero drag at $\beta = 0^\circ$. Reproduced from reference 5.

L-1722

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FLIGHT-TEST INVESTIGATION OF A MODEL OF AN AERIAL VEHICLE SUPPORTED BY FOUR UNSHROUDED PROPELLERS. Robert H. Kirby. April 1962. 24p. OTS price, $0.75. (NASA TECHNICAL NOTE D-1235)

A dynamic stability and control investigation showed that the uncontrolled hovering motions of the model were unstable oscillations in pitch and roll. However, inasmuch as the periods of the oscillations were relatively long, the model could be controlled fairly easily in hovering without artificial stabilization. The basic model was difficult to control at the higher forward speeds of the investigation but was easy to fly when horizontal and vertical tails were added.

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